WHITE PAPER

Intelligent Air Quality Beyond CO_2 for Indoor Air Quality Monitoring and Demand-Controlled Ventilation

Content Guide

1 Introduction

John is a postman in New York.

He spends 10 hours a day in traffic, to deliver parcels or commute. In his free time, he likes to play outdoor sports or videogames in his modern apartment in town.

Dorothy is an elderly lady living in an old house just outside the city of Lyon, in France.

She spends most of her time at home cooking and cleaning, but still very mindful of her looks and always wearing some makeup, whether she plans to meet her friends or not.

If we consider their lifestyle, who of those two people is more exposed to air pollution? Many would answer John, as he spends a lot of time outside in traffic and lives in town.

Well, it is not necessarily true.

Dorothy may have old furniture and painted walls releasing formaldehyde, cook on gas-fuelled stoves producing nitrogen dioxide and carbon monoxide, clean with detergents containing ammonia and chlorine, and use cosmetics which release hydrocarbons.

Without proper ventilation and purification, indoor air can carry dangerous levels of pollution and cause severe health issues, independently of the external air pollution.

This paper will walk you through the anatomy of indoor air and offer advanced solutions to maximize the efficiency of ventilation and air purification systems while maintaining good general air quality.

2 The Anatomy of Indoor Air

Air is composed of 78% nitrogen, 21% oxygen and 1% traces of other gases. In indoor spaces, human activities and the infrastructure itself introduce additional contaminants (Table 1) such as carbon dioxide (CO_2), carbon monoxide (CO) and a mix of gases, called volatile organic compounds (VOCs).

When indoor air is not sufficiently ventilated, contaminants build up, negatively impacting our health, but also reducing our ability to recall information and maintain productivity.

Table 1: typical indoor air contaminants and their sources.

Contamination Source	**Emission Source**	**Contaminants**
Human Being	Breath	CO_2
		Acetone, Ethanol, Isoprene
		Humidity
	Skin respiration and transpiration	Nonanal, Decanal, α-Pinene
		Humidity

Contamination Source	Emission Source	Contaminants
	Flatus	Hydrogen, Methane
	Cosmetics	Limonene, Eucalyptol
	Household Supplies	Alcohol, Esters, Limonene
	Combustion (Engines, Appliances, Tobacco Smoke)	Carbon Monoxide
		CO_2
		Humidity
Building Material, Furniture, Office Equipment, Consumer Products	Paints, Adhesives, Solvents, Carpets	Formaldehyde, Alcanes, Alcohols, Carbonyls, Ketones, Siloxanes
	PVC	Toluene, Xylene, Decane
	Printers, Copiers, Computers	Benzene, Styrene, Phenole

2.1 The Role and Impact of VOCs in Indoor Air

According to the World Health Organization, household air pollution is one of the leading causes of diseases and premature death in the developing world[1].

About 5,000 to 10,000 different VOCs are generated by building materials, furnishings, office equipment, consumer products, cooking and bio-effluents (as a result of human respiration, transpiration, and metabolism).

As a matter of fact, those VOCs are two to five times more likely to be found indoors than outdoors which makes them a dominant contaminant of indoor air. VOCs are known to cause eye irritation, headache, drowsiness, or even dizziness, also known as Sick Building Syndrome (SBS). Prolonged exposure can lead to serious illness or even death.

The WHO has made a significant contribution to raise awareness on how important good air quality is to our well-being, and has issued a list of common indoor air pollutants and their potential risks to drive policy making (Table 2).

Table 2: Indoor air pollutants and associated risks (WHO, 2009)

Indoor pollutant	Risk
Benzene	Acute myeloid leukemia, genotoxicity
Carbon monoxide	Acute reduction of exercise tolerance, increase in symptoms of ischemic heart disease
Formaldehyde	Sensory irritation, impact on lung function, nasopharyngeal cancer, myeloid leukemia

[1] https://www.who.int/health-topics/air-pollution

Indoor pollutant	Risk
Naphthalene	Respiratory tract lesions, inflammation and cancer of airways
Nitrogen dioxide	Respiratory symptoms, bronchoconstriction, airway inflammation and decreases in immune defense
Polycyclic aromatic hydrocarbons	Lung cancer
Radon	Lung cancer, associated to leukemia and cancers of the extra thoracic airways
Trichloroethylene	Liver, kidney, bile duct cancer and non-Hodgkin's lymphoma
Tetrachloroethylene	Early renal disease and impaired kidney performance

Indoor-generated VOCs are not only dangerous when directly inhaled, but indirectly increase outdoor air pollution too. Even though people use 15 times more gasoline and diesel than household products (in weight), cosmetics, cleansers and hairsprays contribute to 38% of fine particulates and smog[2].

2.2 The Role and Impact of CO_2 in Indoor Air

Public regulation sets limits of exposure to CO_2 in offices and working environments. For example, the US Occupational Safety and Health Administration (OSHA) sets a Permissible Exposure Limit (PEL) for CO_2 to 5,000 ppm over an 8-hour workday.

Overexposure to CO_2 can lead to problems with concentration, an increased heart rate, breathing issues, headaches, and dizziness (Figure 1).

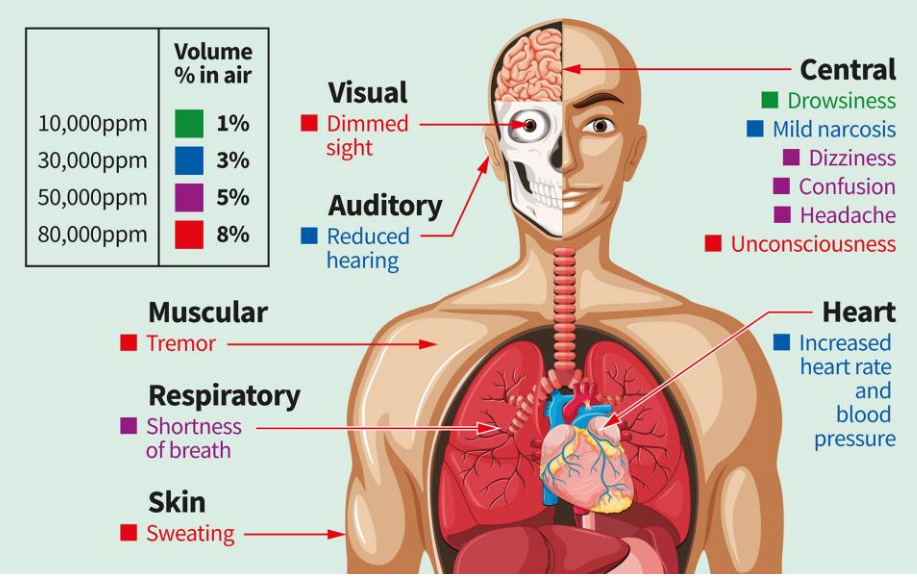

Figure 1: Impact of CO_2 on the human body.

[2] McDonald et al., Science (2018) Volatile chemical products emerging as largest petrochemical source of urban organic emissions

Traditional DCV systems use CO_2 sensors to monitor occupancy levels and adjust ventilation accordingly (Figure 2).

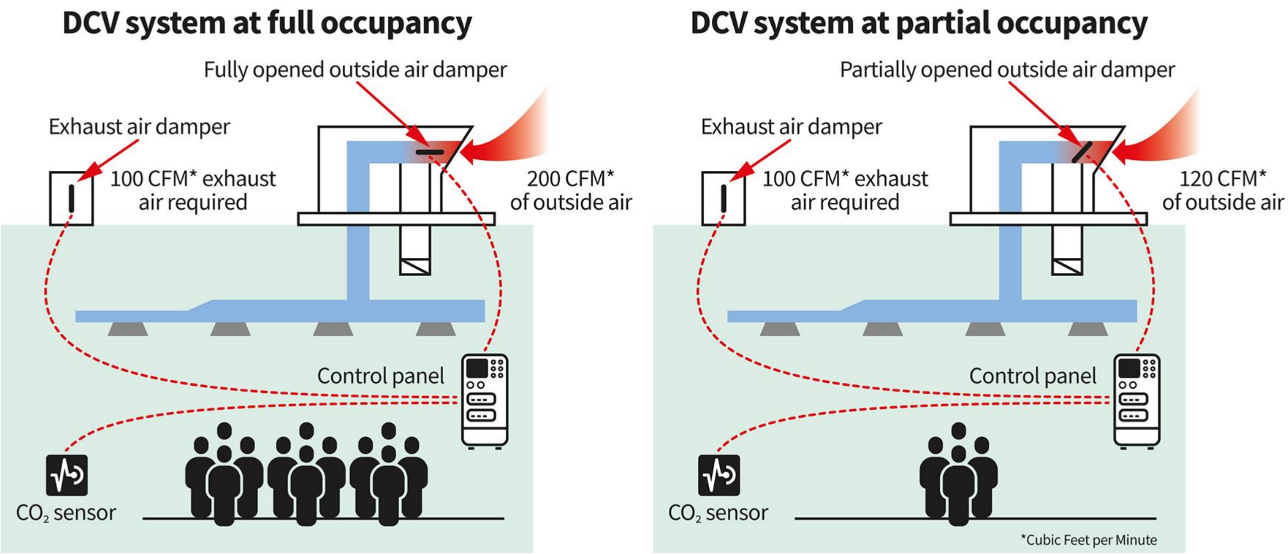

Figure 2: CO_2-regulated DCV systems.

If we look at specific ventilation guidelines, such as those issued by the German Environmental Agency (UBA), we see that the CO_2 limit, at which air is considered bad and ventilation is required, is set at 1,500 ppm.

This significantly lower limit than the OSHA guidance not only provides a safety margin, but also harks back to historic practices of ventilation and air quality measurement.

For a long time, CO_2 was the only indoor air pollutant whose concentrations could be measured at an affordable cost. In the 19th century, Max von Pettenkofer proved that a correlation exists between CO_2 and VOC concentration levels in living environments, thus making CO_2 a suitable surrogate for VOCs when assessing indoor air quality.

This explains the ubiquity of CO_2 sensors in demand-controlled ventilation (DCV) systems nowadays, and their use to contain contamination from air pollutants.

So, can we conclude that monitoring CO_2 only, and keeping its concentration within limits, guarantees low levels of VOC pollutants?

Well, not really.

Let's take, for example, household rooms like a bathroom or a kitchen, or public spaces like gyms. In these cases, human activities generate an excess of VOCs (from bio effluents or cooking food) which is not reflected by an increase in CO_2 levels. This means that traditional DCV systems cannot always guarantee good air quality. To read more on this topic go to section 5.

3 ScioSense Approach – Intelligent Air Quality Beyond CO_2

Backed by decades of experience in environmental sensors for automotive, industrial and consumer applications, we in ScioSense have developed fully integrated solutions for VOC concentration measurements to enable demand-controlled ventilation systems, air purifiers and smart devices to truly meet user demand for good air quality in households and public spaces.

ScioSense indoor air quality sensors process raw measurements from multiple gas sensing elements through advanced sensor fusion algorithms to output a series of air quality indicators, adhering to various international, as well as industry standards.

Unlike other commercial solutions, ScioSense ENS160 provides ready-to-use, standard outputs which do not require further host computation (Table 3). A simple register reading is required to obtain air quality indexes, VOC levels or CO_2 estimates. This makes ENS160 a standalone solution for monitoring air quality and notifying significant events on demand, while the host MCU can focus on other system tasks or remain idle.

Table 3: ENS160 outputs

Air Quality output signal	Description
TVOC	Total Volatile Organic Compound concentration, measured in parts per billion (ppb). Returns the total concentration of VOCs in the air. ScioSense follows international classification criteria and mixture references (e.g. ISO16000-29) for design and calibration of its products. Our TVOC signal ranges from 0 to 65,000 ppb
eCO_2	Equivalent CO_2, measured in parts per million (ppm). Returns the estimated CO_2 concentration based on VOC levels (“Reverse Metabolic Rule”)
AQI	Air Quality Index, measured in levels 1 to 5. Returns a configurable air quality index as defined by national or international regulatory bodies.

3.1 TVOC as an Effective Indoor Air Quality Indicator

TVOC measures the Total Volatile Organic Compound concentration, and is used by several countries as an indicator of indoor air quality. Limits and recommendations are based on a large number of studies correlating health issues to prolonged exposure to high TVOC levels.

The German Environmental Agency, for example, sets to 1 mg/m^3 the maximum acceptable TVOC concentration compatible with a healthy living environment (Table 4).

ScioSense gas sensors are designed to detect a broad set of VOCs commonly present indoors, including but not limited to those indicated by the WHO as important pollutants (Table 2)[3].

[3] Except for Radon, which is an inert radioactive gas whose detection requires dedicated technologies

Table 4: Recommendations according to German Federal Environmental Agency standard (Umweltbundesamt or UBA) based on TVOC levels.

AQI-UBA		TVOC		Hygienic Rating	Recommendation	Exposure Limit
#	Rating	mg/m^3	ppm			
5	Unhealthy	10-25	2.2-5.5	Situation not acceptable	Use only if unavoidable Intensified ventilation recommended	Hours
4	Poor	3-10	0.65-2.2	Major objections	Intensified ventilation recommended Search for sources	<1 month
3	Moderate	1-3	0.22-0.65	Some objections	Intensified ventilation recommended Search for sources	<12 months
2	Good	0.3-1	0.065-0.22	No relevant objections	Sufficient ventilation recommended	No limit
1	Excellent	<0.3	0-0.065	No objections	Target	No limit

TVOC signals are often used in DCV systems, air purification and smart devices to finely control ventilation and display air quality levels over time to increase user awareness.

Besides accuracy and sensitivity, system responsiveness is another key sensor requirement in these applications to provide a satisfactory user experience.

3.2 eCO_2 as an Effective Indoor Air Quality Indicator

As a compromise to the common use of CO_2 to indicate air quality, ScioSense gas sensors provide equivalent CO_2 (eCO_2) readings which should not be confused with CO_2 measurements. eCO_2 is calculated by using the "Reverse Metabolic Rule" (reversing the "Pettenkofer law" to achieve signal compatibility between eCO_2 and CO_2) while considering the proportional correlation of VOCs and CO_2 as well.

ScioSense gas sensors are designed to accurately estimate CO_2 concentrations following this rule, thus providing a very close match to the response of dedicated CO_2 sensors (Figure 3).

We call the obtained output signal eCO_2 or equivalent CO_2, expressed in parts per million (ppm).

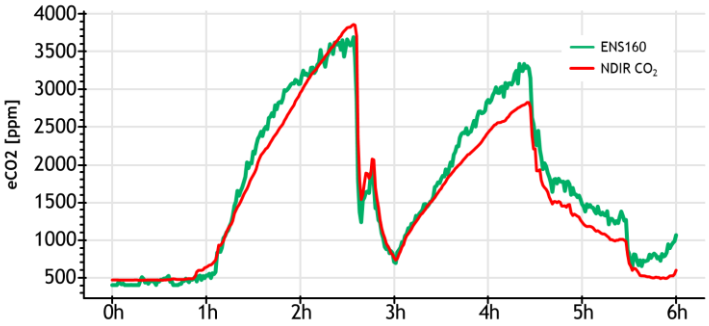

Figure 3: Comparison between ScioSense ENS160 eCO_2 readings and NDIR CO_2 outputs.

The major advantage of eCO_2 over pure CO_2 measurements is its ability to capture odors and bio-effluents that are completely invisible to CO_2 sensors. Figure 4 compares the eCO_2 output from ScioSense ENS160 to an NDIR CO_2 sensor in some indoor environments: ENS160 closely tracks CO_2 levels when human presence is the dominant contributor of CO_2, but in addition accurately reports VOC events which an NDIR CO_2 sensor would not detect.

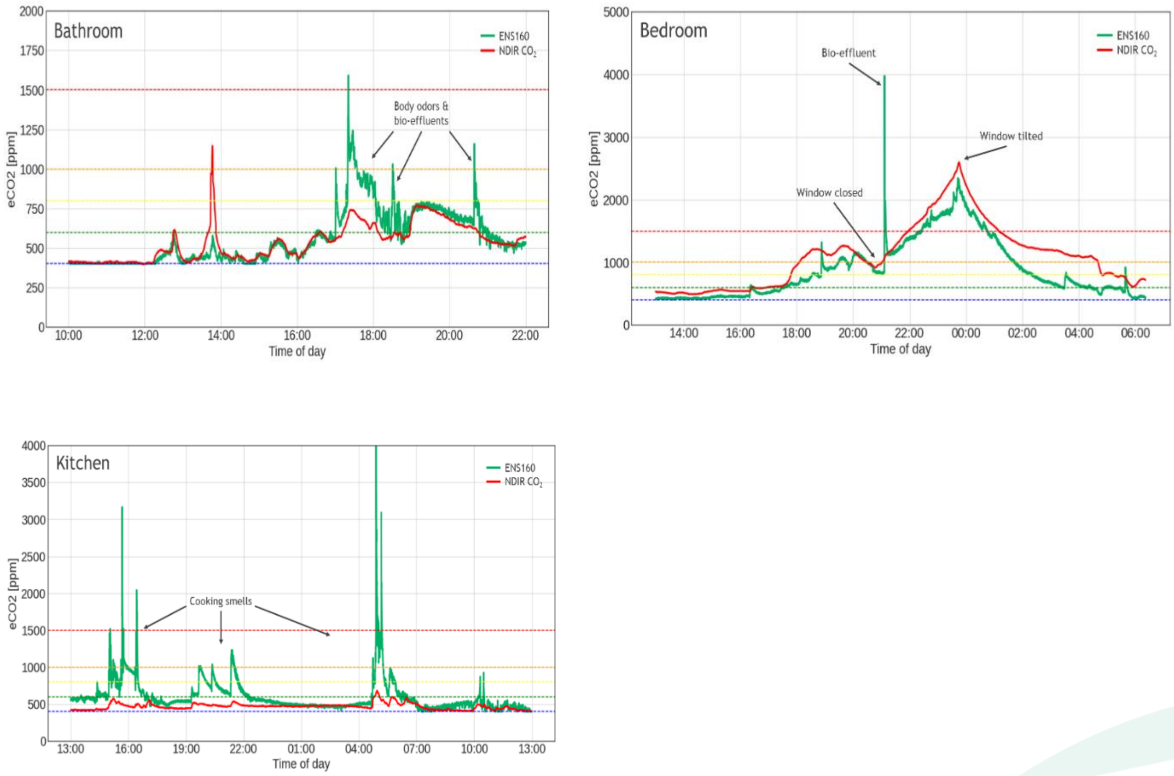

Figure 4: eCO_2 reading of a ScioSense VOC sensor compared to NDIR CO_2 selective sensor. The VOC sensor detects body odors and bio-effluents common in bathroom, bedroom and kitchen environments which are not detected by a selective NDIR CO_2 sensor.

3.3 Air Quality Index – Smart Air Quality Indicator

Many smart home and smart building applications require a simple air quality classification.

ScioSense gas sensors offer an Air Quality Index (AQI), based on internationally recognized standards. AQI-UBA is a ready-to-use air quality index as defined by the German Federal Environmental Agency and widely used by many countries and organizations (Table 4).

The AQI is computed directly by ENS160 without the use of external libraries. This gives a unique flexibility and convenience in providing direct ventilation recommendations.

4 Debunking some myths

A very frequent inquiry on air quality sensors is about their accuracy, especially relative to specific gases of interest, such as CO_2.

4.1 Accuracy on single gases is not meaningful

Measurement accuracy on single gases is performed in artificial atmospheres, where the gas of interest is introduced at a known concentration. As a broadband air quality sensor does not detect each gas separately and selectively, cross-sensitivity plays an important role. The accuracy of the Total VOC measurement depends then on the specific gas mix and cannot be inferred from the sum of individual single gas measurements.

As in the computer example, real application benchmarking is to be considered more representative of the true performance of an air quality sensor. For this reason, in the automotive industry, these type of sensors are generally evaluated through test drives in specific but real case scenarios (e.g. stop at a traffic light, ride in the countryside, passing through a tunnel, parking in an underground garage).

4.2 Accuracy in measuring a proxy gas is not meaningful

Occupancy detection is traditionally performed by measuring CO_2 levels between 0 and 2,000ppm. At these concentrations, CO_2 is not dangerous, as Figure 1 shows, and there is no reason to detect it other than to apply the metabolic rule and infer the amount of VOCs present in the air. As already shown, this rule breaks down in common real case scenarios (see Figures 3 and 4), so the accuracy of CO_2 measurements does not reflect the performance of the system regulated by them.

The equivalent CO_2 output of ScioSense air quality sensors is based on the direct detection of VOCs – the actual cause of the sick building syndrome – and translates it into CO_2 concentration values for easy design migration from traditional NDIR CO_2 sensors.

4.3 The reference for the accuracy is not accurate

NDIR CO_2 sensors are often regarded to as standard choice for occupancy detection, especially in demand-controlled ventilation systems. As a matter of fact, NDIR CO_2 sensors are not highly accurate, display performance degradation over time, and should not be used as reference to benchmark air quality sensors (Figure 5).

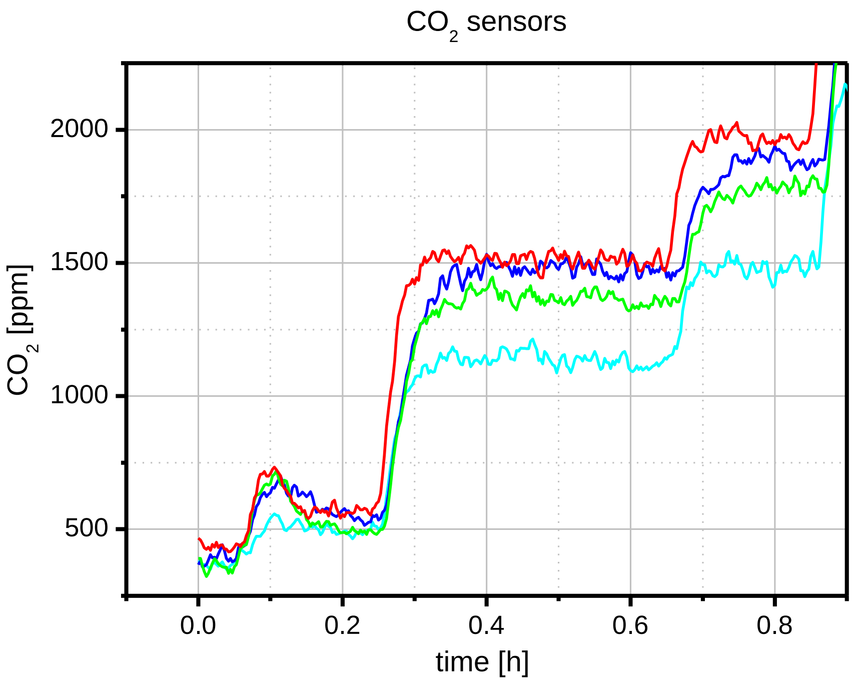

Figure 5: Device-to-device variation of NDIR CO_2 sensors of the same type and age

5 Our recommendations

Modern ventilation and air purification systems are expected to monitor and guarantee good air quality. It is not only CO_2 levels that need to be suppressed to prevent loss of attention and dizziness: air pollutants also need to be removed through filtering and ventilation to prevent health problems.

Demand-controlled ventilation (DCV) systems use the key parameters of CO_2, VOC, temperature, and humidity to control air quality in an energy-efficient way.

Experiments demonstrated that a DCV system mounted in a gym showed 24% less operating time amounting to an overall 60% savings in total costs, while resulting in good air quality ratings from users[4].

The ScioSense ENS160 VOC sensor, in combination with ENS210 temperature and humidity sensor, provides an accurate, complete, and compact solution for air quality monitoring, enabling the development of effective, energy-optimized systems tuned to the characteristics of indoor spaces.

Table 5: ScioSense ENS160 gas sensor

ENS160 characteristics	Customer benefits
Fully integrated solution (sensing, control, processing, communication)	Easy integration, consistent performance, minimum system requirements, lower overall power consumption, short time-to-market.

4 https://www.researchgate.net/publication/314443024_Impact_of_demand_controlled_ventilation_on_indoor_air_quality_ventilation_effectiveness_and_energy_efficiency_in_a_school_building

ENS160 characteristics	Customer benefits
Output signals are based on standards and ready to use: TVOC in ppb, eCO_2 in ppm, AQI as scale	No computational load on host or software integration/updates. Direct reference to national/international regulation simplifies communication to customers and end users.
High stability against humidity	Consistent response over wide operating conditions and over time.

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